U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN No. 17.

B. T. GALLOWAY, Chief of Bureau.

SOME

DISEASES OF THE COWPEA.

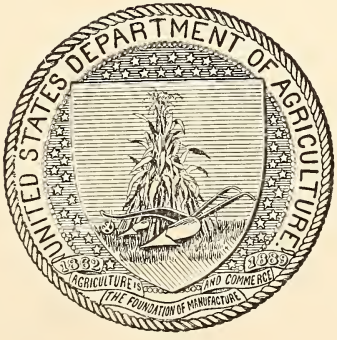
I. THE WILT DISEASE OF THE COWPEA AND ITS CONTROL.
By W. A. Orton, *Assistant Pathologist.*

II. A COWPEA RESISTANT TO ROOT KNOT (Heterodera radicicola).
By Herbert J. Webber, *Physiologist*, and W. A. Orton, *Assistant Pathologist.*

VEGETABLE PATHOLOGICAL AND PHYSIOLOGICAL INVESTIGATIONS.

PATHOLOGICAL AND PLANT BREEDING LABORATORIES.

Issued April 22, 1902.



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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., January 20, 1902.

Sir: I have the honor to transmit herewith two papers, one entitled The Wilt Disease of the Cowpea and its Control and the other A Cowpea Resistant to Root Knot, and respectfully recommend that they be published as Bulletin No. 17 of the Bureau series, under the general title Some Diseases of the Cowpea. The papers were prepared, respectively, by Mr. William A. Orton and Mr. H. J. Webber, both of Vegetable Pathological and Physiological Investigations, and were submitted by the Pathologist and Physiologist.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

Among the diseases of plants most difficult to deal with are those which attack the roots. For a number of years this office has been investigating such diseases and has published several bulletins in regard to them. Among these diseases is the wilt of cotton, which spread so rapidly over many valuable cotton areas as to render cotton growing impossible on the infected soil. Mr. William A. Orton, the author of the first paper of this bulletin, was sent to South Carolina in 1899 to inaugurate a series of investigations with a view of finding a means of controlling this wilt. He found, as a result of the first year's work, that it would be impracticable to destroy the fungus by any method of treating the soil. In the course of his investigations, however, his attention was called to the fact that certain plants were resistant to the wilt, and by selecting such plants he obtained a number of strains of the best varieties sufficiently resistant to the disease to be grown on the worst infected lands.

The first part of the present bulletin deals with a disease of cowpeas closely related to the wilt disease of cotton. This is so prevalent in certain areas as to render the growth of the cowpea, which is one of the most valuable rotation crops, impossible in such areas. Working on the principle of the resistance of certain plants, as in the case of cotton, a variety of cowpea, known as the Iron, which is resistant to the disease, has been found, and no doubt other resistant varieties will be obtained. The second part of the bulletin deals with the so-called eel worm, or root nematode. This attacks the roots of the cowpea and causes them to swell and become distorted, thus preventing normal healthy growth. The ordinary varieties are peculiarly sensitive to this trouble, and as the same eel worms attack many other crops there is danger of these becoming infested where the cowpea is used as a rotation crop.

ALBERT F. WOODS,
Pathologist and Physiologist.

OFFICE OF THE PATHOLOGIST AND PHYSIOLOGIST,
Washington, D. C., January 20, 1902.

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SOME DISEASES OF THE COWPEA.

I. THE WILT DISEASE OF THE COWPEA AND ITS CONTROL.

By W. A. Orton, *Assistant Pathologist.*

INTRODUCTION.

The investigation of the wilt disease of the cowpea was undertaken by the writer in connection with similar work on the wilt of cotton and watermelons, begun in 1899. These diseases had previously been studied by Dr. Erwin F. Smith, of this Department, and in Bulletin No. 17[1] of the Division of Vegetable Physiology and Pathology the results were given of extensive investigations, showing the cause of the disease, and the nature, habits, and relationships of the fungus producing it.

The efforts of the writer have been directed mainly toward the solution of some problems necessarily left unfinished by Dr. Smith, and especially toward finding a practicable remedy for the disease. This work has resulted in the discovery of a race of cowpea resistant to the attacks of the wilt fungus, and the experiments carried on by the Department indicate that it will be possible by careful selection to obtain other races adapted to different uses. The work has not yet been completed, but it is believed that the results already obtained justify publication, since the suggestions offered will afford relief to the farmers who have been troubled with the cowpea wilt, and because they may suggest methods that will also be useful in combating other diseases than the one treated here.

DESCRIPTION OF THE DISEASE.

The disease first appears when the plants are about six weeks old. Up to this time they will grow very well and appear perfectly healthy. Scattered plants then begin to drop their leaves, the lower ones falling first. Growth is checked, and the stem shows a faint reddish-brown tinge. After the leaves have fallen the stem becomes dead and covered with a light-pink coating of the spores of the wilt fungus (Pl. I). The spread of the disease is more gradual and less conspicuous in the early part of the season, but after the peas begin to set fruit they succumb very rapidly, and a field that in July may promise a fine

[1] Smith, Erwin F., Wilt Disease of Cotton, Watermelon, and Cowpea, 1899.

crop may be entirely dead before September without having matured a pod. The disease usually appears in spots, like the cotton wilt, and these diseased areas spread until they may cover a whole field.

In moderate cases, or where the varieties planted are less subject to the disease, only the weaker plants are killed, while the rest are dwarfed and their yield reduced. A careful examination of the roots will show that many of the small lateral roots are dead and small tufts of roots mark the points of infection (fig. 1). This tufting of the rootlets is similar to that produced on cotton by the cotton-wilt fungus.

In all cases the vascular tissue of the stem is brown, and the disease may be clearly distinguished by cutting across the stem and observing whether the color of the wood is normal. This discoloration is characteristic of this class of diseases. The term "wilt" is somewhat misleading, as the leaves usually drop off before there is any conspicuous wilting. The name was applied because of its relationship to the wilt of cotton and watermelons, where this symptom is very prominent, and it has seemed desirable to retain it for the cowpea disease.

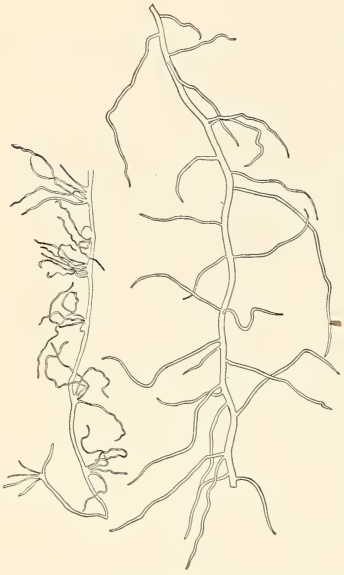

FIG. 1.—Roots of diseased cowpea, showing tufts produced by the wilt fungus, compared with healthy root.

CAUSE OF THE DISEASE.

The disease is caused by a fungus, *Neocosmospora vasinfecta*, var. *tracheiphila*, Erw. Sm.[1] It enters the plant from the soil through the smaller roots and grows through the water ducts of the stem until it may be found, in advanced cases, even in the smaller branches and the petioles of the leaves. The brown color of the wood is due to the action of the fungus on the walls of the vessel it occupies. The mycelium is nearly white, but it causes the walls of the vessels to become deeply stained. The fungus is not found outside of the water vessels while the plant is living. It is present within them in considerable quantities. Some of the vessels are completely filled with the interwoven hyphæ of the fungus, and the supply of water and plant food carried from the roots to the leaves is greatly diminished. The appearance of the plant affected by this disease indicates that it is suffering from a lack of water. Rains at this stage do not help it, however, and usually only a few days elapse after the disease appears before the plant is dead.

[1] Described in Bul. 17, Div. Veg. Phys. and Path. Smith, Erwin F., Wilt Disease of Cotton, Watermelon, and Cowpea, 1899.

DESCRIPTION OF THE FUNGUS.

The following is a detailed description of the fungus:

The mycelium is 2–4 μ in diameter, septate, and branching freely. Its color inside the plant is hyaline or nearly so, but in pure cultures on certain media it becomes bright red or purple.[1] It produces spores (micro-conidia) inside the vessels of the living stem by abstriction from branches of the mycelium. They are hyaline, oval to narrowly elliptical, 4–25 μ by 2–6 μ, nonseptate, or sometimes uniseptate after abscission. The presence of these small conidia inside the water vessels affords a reliable means of distinguishing between this fungus and other species which may be found in the stems of diseased plants.

Other spores (macro-conidia), the *Fusarium* stage of the fungus, are borne in great profusion on the outer surface of the dead stems, or on dead, sunken spots on badly diseased stems, on small, oval conidia beds, consisting of short, irregular conidiaphores that are outgrowths of the internal fungus, as shown by the fact that the conidia beds are borne in parallel rows, which correspond to the vascular bundles inside the stem. The spores are lunulate, 3–5 septate, 30–50 μ by 4–6 μ, hyaline when examined separately, but in mass varying from nearly white to pink or deep salmon color.

The ascomycetous stage of the fungus is found on the roots of the dead plants, or occasionally on the parts above ground. The perithecia are small, bright-red bodies, borne singly or several together on the outer surface of the roots, ovate, variable in size, 250–350 μ by 200–300 μ; asci numerous, 8-spored, cylindric, stipitate; ascospores in one row, globose to short elliptical, rather thick-walled, colorless till ripe, then light brown, variable in size, 10–12 μ in diameter.

The cowpea fungus produces its perithecia very freely on dead plants, and the writer has also found them on the root tubercles of healthy plants of the Iron cowpea growing on infected land. The watermelon fungus produces perithecia less freely and apparently only under certain conditions or when at a certain stage of decay, while the cotton fungus forms them still more sparingly. Cultures made from ascospores of the cowpea fungus will reproduce ascospores in a week's time when grown on the proper media.

MANNER OF INFECTION AND SPREAD.

The fungus enters the plant through the small roots, producing on them little tufts which seem to be characteristic of this class of diseases. The manner in which the cowpea fungus spreads has not been fully investigated, but as far as now known it is like the cotton and watermelon wilts, which have been studied more carefully. The diseased areas in the fields increase in size quite rapidly by direct growth from the edges, which is probably due to the spread of the mycelium through the soil, though no experiments have been made to demonstrate this. The cotton fungus is carried by the plow and cultivator, as evidenced by its spread down the length of a field from a diseased area at one end, in cases observed by the writer; and by cattle, in cases where they passed through an infected field on their way to

[1] Smith, Erwin F., l. c., p. 14.

pasture. The watermelon fungus has been observed to spread from high to lower lands through the drainage water. The cowpea fungus produces spores in the greatest abundance, and there is every reason to believe that it spreads in all these ways.

It is difficult to account, by any of the causes just mentioned, for isolated outbreaks of the disease, which occur frequently where it had not been observed before. The fungus is undoubtedly widely distributed in places where it ordinarily causes little or no damage until some favorable conditions lead to an unusual development of it. The fact that the disease may occur in small quantities in a field without being noticed makes preventive measures, designed to limit the spread by destroying diseased plants, very nearly impracticable.

RELATION TO OTHER WILT DISEASES.

As already stated, the wilt of cowpea is closely allied to similar diseases widely prevalent on cotton, okra, watermelon, and other plants. The fungi causing these other diseases are considered to be varieties of the same species. As far as the appearance of the parasite is concerned there is no difference. When grown in pure culture, they can not be distinguished from each other. The manner of infection seems to be the same in all, and the effects produced are quite similar in all cases. The different diseases occur in nearly the same territory. It is well demonstrated, however, that they are not intercommunicable, i. e., the cowpea disease attacks nothing but cowpeas, the watermelon wilt nothing but watermelons, the cotton wilt only okra and cotton. The cross inoculations from pure cultures of the different fungi, reported by Dr. Smith[1] were all unsuccessful. Some experiments made by the writer of grafting pieces of diseased cowpea stems into cotton plants and vice versa were also unsuccessful. The writer has seen cowpeas perfectly free from disease in a very large number of cotton fields where the cotton wilt was present, and in several instances cowpeas have been observed to do well when grown in fields where watermelons were dying from wilt.

In Monetta, S. C., cowpeas thrive where watermelons die from wilt, and cotton does well where cowpeas are all killed. In Dillon both the cotton and cowpea are affected, while watermelons are healthy on the same land. It frequently happens that more than one of these diseases occur in the same field, but it has never been proved that one disease induces another. One instance, at least, has come to the attention of the writer where, at Salters, S. C., the three wilt diseases of cotton, watermelon, and cowpea all occurred in the same field. In the majority of cases, however, the occurrence of the disease on the different plants is sufficiently distinct to leave no doubt that they are noncommunicable.

[1] Smith, Erwin F., l. c., p. 35.

DISTRIBUTION.

The disease is known to occur in North Carolina, South Carolina, and Alabama, and there is every probability that it will also be found in other States where cowpeas are grown. In South Carolina, where most of the investigations of this Department have been carried on, it has been found widespread in the counties of Aiken, Darlington, Saluda, Marion, Williamsburg, and Charleston. In all these cases it has been found to be more prevalent on sandy soils and in the higher, better drained portions of the fields, rather than in the lower and stiffer soils. In this respect it is like the cotton wilt and the watermelon wilt, which are both more injurious on sandy soils than on clay. It may occur on clay soils also, but it is believed the regions in greatest danger from the disease are the coast region, the pine belt, and sand hills, from North Carolina to Louisiana. It is to be looked for throughout this area. The writer has not had the opportunity of examining all this territory, but he has found the disease wherever he has searched for it and believes that futher observations will extend the area known to be infected with it.

EXTENT OF LOSS.

The disease has not yet become sufficiently widespread to cause serious loss except in a few localities, though the aggregate injury from it throughout the country must be very considerable. It is already a serious annoyance in many places and there is great danger of its future spread. This danger is emphasized by the recent rapid spread of the cotton wilt, a closely related disease, which is yearly becoming more prevalent and now causes immense damage in North Carolina, South Carolina, Georgia, Alabama, Mississippi, and Louisiana. If conditions favor its development and the proper means are not taken to check it, the cowpea wilt may become equally widespread and proportionately injurious.

The growing tendency toward diversification and rotation of crops in the South is leading to a much wider use of the cowpea than formerly and makes an understanding of its diseases of great importance.

The cowpea is the principal leguminous crop of the South. It is grown for hay, for forage, and for the crop of seed, but more than for any other reason because of its value as a fertilizer and soil renovator. In this use it fills one of the greatest needs of the South, where the hot summer sun hastens the destruction of the organic matter in the soil and the heavy rains leach out the soluble plant food from lands left unprotected through the winter. The fertility of the land can best be maintained by growing cowpeas or related plants and plowing them under to increase the amount of humus in the soil, or, better still, by feeding them to stock and returning the manure to the soil. The cowpea, in common with other plants of the bean family, is able to

draw a part of its nitrogen from the air, so that the soil is left not only richer in vegetable matter than before, but richer in the most expensive fertilizing element, nitrogen, and the farmer need apply only the potash and phosphoric acid. A crop of cowpeas also improves the mechanical condition of the soil by the opening and loosening effect of its deep-feeding roots.

The cowpea succeeds well under widely diverse conditions of soil and climate, from the rich alluvial lowlands to the most barren and worn-out hillsides, and from the extreme South to the Central and Northern States. The methods of cultivation vary, but it is essentially a supplementary or intermediate crop. It is very often planted between the corn rows at the last cultivation, or it is sown broadcast or in drills, after grain or some early maturing crop has been removed. It is an excellent crop for planting in orchards and is much used for this purpose in the peach-growing districts. It is used in the trucking sections for planting between the rows of asparagus and to occupy the ground after an early spring crop is taken off.

Where the wilt disease is present in the soil, the injury to a second crop of cowpeas is likely to be much greater. It should be possible to grow cowpeas nearly every year on the same land, alone or in connection with other crops, but where the wilt fungus is present the peas die, and the farmers, with a partial understanding of the cause, say the land is "pea sick." The real reason for the failure of the peas is not the deficiency of any fertilizing elements, but because successive crops of cowpeas have so increased the amount of the wilt fungus in the soil that the ordinary varieties can not live. This "pea sickness" is believed to be due, in South Carolina at least, to the wilt disease, though sometimes peas are injured by the root nematode, or by a borer in the stem. The writer has known several instances where the wilt caused practically a complete destruction of the crop, but in the majority of instances only part of the plants were killed or only small areas in the field were badly attacked. Where peas are planted again on such land the injury is much greater. How long the land remains infected is not known in the case of the cowpea wilt, but the cotton-wilt fungus has been found in the soil after seven years in other crops, and probably is able to live for a much longer time. In the case of the cowpea, the amount of the wilt is greatly diminished when other crops intervene, according to the experience of Mr. T. S. Williams, who believes that rotation of crops will prevent serious loss from the wilt.

In many cases, however, it is desirable to grow cowpeas on the same land for several years, especially in orchards and on lands which it is desired to bring to a higher state of fertility. The occurrence of the wilt on such land prevents this from being done successfully. Even in the ordinary farm rotation cowpeas are often grown more than one

year on the same land. For instance, the rotation most often recommended for the South by the best authorities is corn, with cowpeas between the rows; winter oats or wheat, followed by cowpeas; cotton.[1] From the nature of the disease, the writer doubts whether such a rotation as this would prevent injury from the cowpea wilt, if the ordinary varieties were grown, and believes that under present farm conditions the disease may become generally prevalent.

PREVENTIVE MEASURES.

ROTATION OF CROPS.

Where rotation is practiced there is less trouble with the disease. One or two years of other crops will reduce the amount of the disease so that it will not cause serious loss, though this relief is only temporary, as it is very doubtful whether the soil can be freed of the fungus in this way. It is probable that where a suitable rotation of crops is practiced this disease will not be very troublesome, but it has already been pointed out that there are many circumstances where it is desirable to grow cowpeas as a secondary or intermediate crop more or less continuously on the same land, and there are also many lands so badly infected with the fungus that ordinary rotation of crops will not be sufficient, and some other means of control must be adopted or the farmer will have to give up the growing of cowpeas.

SUBSTITUTION OF OTHER CROPS.

The alternative is left of growing some other leguminous crop, as in the experiments and observations of the Department no crop except the cowpea has been affected by this wilt disease. In many cases this can be done to good advantage, and unquestionably Southern agriculture would be benefited if a greater variety of legumes were used, but it must be admitted that no other crop adapted to Southern conditions can fully take the place of the cowpea, since no other can be put to such a variety of uses.

Among the forage plants tested by the Department the one most to be recommended as a substitute for the cowpea is the velvet bean. This is not subject to the wilt, but is somewhat liable to the attacks of the root-knot worm or nematode. It produces a heavy growth of forage and makes excellent hay, or plowed under makes a valuable fertilizer. It covers the ground well, and is superior to the cowpea for shading out grass. Its defects are that it requires a long season and does not ripen seed except in the extreme South, and the seed is expensive to buy. Its trailing habit and long runners make it difficult to cut and make into hay and hard to plow under, while it is objectionable in orchards on account of its tendency to climb into the trees.

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[1] Tracy, S. M., Farmers' Bulletin, No. 81.

The soy bean and Florida beggar weed may be used for hay as a summer crop, or hairy vetch may be sown in the fall. All these crops have in common the disadvantage of being unfamiliar to the average farmer, and consequently will be slow to come into general use, while the cowpea is cultivated and its use understood everywhere.

In view of the fact that rotation of crops is not always a practicable remedy and that there is no complete substitute for the cowpea, the value of a cowpea resistant to the disease is easily understood.

The possibility of combating the wilt in this way was suggested by the success of similar methods in dealing with the cotton wilt (see Bulletin 27, Division Vegetable Physiology and Pathology).[1] and it was learned from Mr. T. S. Williams, of Monetta, S. C., that a variety known as the Iron cowpea, cultivated by him, was resistant to the disease. Mr. Williams wrote August 25, 1900:

> I think you are working along the right line in trying to get a variety of melon with strong resistance to wilt. * * * I have a pea called the Iron pea, which is practically impervious to the pea wilt, or, as we call it, "pea sickness." This pea will make a fine crop on lands where peas have been planted a number of years and where other kinds will all die.

The writer visited Mr. Williams later in the season and saw the fields in question. The Iron pea was making a vigorous, healthy growth where other varieties had died the year before. The roots of these peas were examined and in many cases showed the little tufts of roots that indicate the presence of the wilt fungus in the soil. Occasional plants were found to be diseased and to have the perithecia of the wilt fungus on their roots. In one field where the Iron pea was growing by the side of the common field cowpea the Iron pea was healthy, while the other died very badly from the wilt disease. No nematodes were found in any of these fields. A neighbor of Mr. Williams, who for two years had all his peas die, planted the Iron pea this year (1901) at Mr. Williams's suggestion and made an excellent crop.

EXPERIMENTS WITH COWPEAS AND OTHER CROPS.

Arrangements were made for a careful test of different varieties the following season. This test was made by the Department in cooperation with Mr. Williams at Monetta, S. C., on land thoroughly infected with the cowpea wilt. One and one-half acres were planted May 29, 1901, to a number of varieties of cowpea, soy bean, velvet bean, and some Japanese forage plants obtained through the section of Seed and Plant Introduction of this Department. The soil was sandy, in good condition, and well fertilized. A crop of winter oats had been removed and the land thoroughly prepared. All the varieties tested were planted by hand in the same way, in rows about 3½

[1] Orton, W. A., Wilt Disease of Cotton and Its Control, 1900.

feet apart and 18 inches apart in the hill, two to ten seeds in a hill, according to the nature of the variety. The field was well cultivated. The care taken in planting insured a good stand, and nearly all the plats grew well until July.

Scattered individuals in the different cowpea plats began to show the wilt disease early in July and as the summer progressed more and more succumbed. The amount of injury was increased by the presence in the soil of the root-knot worm or nematode (*Heterodera radicicola*) and by a severe drought in July and the early part of August. These conditions combined to make the test a very severe one.

The presence of the nematode in the soil complicated the problem, and special observations were made to find whether it or the wilt was responsible for the greater injury. The writer believes that the destruction of the cowpea in this experiment was due principally to the wilt fungus, though the damage was undoubtedly much increased by the attacks of the root nematode. The year previous cowpeas on neighboring fields were killed by the wilt and no nematodes found, while in many instances observed by the writer in other localities, where only the nematodes have been present, the injury to cowpeas has been much less.

The velvet beans did very well, making a heavy growth and producing a large crop of seed, which, however, did not mature. They seemed to be completely resistant to the wilt disease.

The soy beans were a disappointment, as they made a very small growth, one foot or so high, and produced only a small crop of seed. They were all badly attacked by the nematode and suffered much from dry weather.

The Japanese cowpeas tested proved to be very early varieties, maturing in two months from planting, when the American sorts were just beginning to blossom. They were small, but quite prolific, and were not greatly injured by the wilt. This was doubtless because of their extreme earliness, as they matured before the disease developed. These varieties would be valuable for trial in the North and for late planting in the South, but for general use they appear to be inferior to the common kinds. At the last they were considerably injured by wilt and the nematode.

Of the American cowpeas, all made a good start and had an equal chance, but none made any crop except the Iron.

A brief account of the behavior of these forage plants as grown on land infected with wilt disease and nematode follows:

Velvet bean (*Mucuna utilis*).—Seed from Florida. S. P. I.[1] Nos. 4333 and 5066, 3 plats. Growth vigorous and heavy. No injury from wilt, but somewhat injured by the root knot. Produced a fair crop of seed which did not mature.

[1]S. P. I. Nos. refer to the serial numbers of the section of Seed and Plant Introduction, which kindly supplied much of the seed used in this experiment.

Soy bean (*Glycine hispida*).—Eight varieties were tried on ten plats. All proved to be immune to the wilt disease, but none of them was adapted to the local conditions. The growth was very small, the plants averaging from 8 to 14 inches high, though most of the varieties bore a good crop of seed for such small plants. All suffered much from drought in midsummer and all were badly injured by the root nematode. On examination of the roots a moderate number of bacterial tubercles were found, indicating that this plant is adapted to tubercle-forming organisms already present in the soil. The soil of the experimental field was a rather light sand and doubtless better results would have been obtained had it been more fertile, as the soy bean requires a richer soil than the cowpea. They were at a considerable disadvantage in this test, on account of the late date of planting and the ensuing dry weather. The soy bean has done well in the South when properly handled, and it is not unlikely that it may rank with the velvet bean as a desirable substitute for the cowpea on wilt-infected land. The writer planted it on Edisto Island, S. C., in 1900, where it made a heavy growth, 3 to 4 feet high, and produced a large crop of seed. It was free from wilt disease there and showed great promise as a forage crop.

The varieties tested at Monetta were as follows:

Best Green, S. P. I. No. 5766.—A late variety. It made a weak growth and suffered much from dry weather and root nematode.

Early Black, from France, S. P. I. No. 5039.—A small and early variety that fruited well, but made a poor growth.

Yoshioka, from Japan, S. P. I. No. 6314.—Early, with dark green and nearly smooth leaves; bore well, but was very small.

Rokugatsu, from Japan, S. P. I. No. 6326.—Early and very small, though bearing well.

Gosha, from Japan, S. P. I. No. 6333.—Early and small; suffered from drought.

Black Round, from Japan, S. P. I. No. 6334.—Early and small, bearing well for its size.

Green Medium, from Japan, S. P. I. No. 6335.—A later variety that made a more vigorous growth and lived through the season, while most of the preceding varieties died in August. It was badly affected by the root nematode.

Bakaziro, from Japan, S. P. I. No. 6336.—Medium early and very prolific, but much injured by drought and nematode.

Lablab Bean (*Dolichos Lablab*), from Japan.—Two varieties tested, the white (S. P. I. No. 6319) and the purple (S. P. I. No. 6320). These beans made a good growth early in the season. Vines long and trailing or climbing high on any support near. They began to blossom in August, but did not mature much seed. Later in the season they were very badly injured by the nematodes.

White Natamane (*Canavalia ensiformis*), from Japan, S. P. I. No. 6323.—A large-leaved, tall climber, blooming early in August and ripening its very large pods about November 1. No traces of wilt. There were plenty of nematode swellings on the roots, but the plants did not appear to be greatly injured by them.

Pink Natamane (*Canavalia gladiata*), from Japan, S. P. I. No. 6324.—Similar to the preceding. Neither these two nor the Lablab beans appear to have any special value as forage plants.

Muroran beans (*Phaseolus mungo-radiatus*), from Japan.—Two kinds were tested, one red (S. P. I. No. 6318) and one green seeded (S. P. I. No. 6321). These beans were very early, maturing in less than two months from planting, and very prolific, but the plants were very small, 8 to 12 inches high, so that they can not be said to have any value as a forage crop for that locality. They evidently require a more fertile soil. No traces of wilt were found. They were badly affected by the root nematode.

Red Fodder peas (*Pisum sativum*), from Japan, S. P. I. No. 6332. These were planted May 29, at the same time as the other forage crops, and would undoubtedly have done better if they had been planted earlier. They made very little growth and suffered from the hot, dry weather. No evidence of infection by the wilt fungus was observed.

A small quantity of the common wild coffee, *Cassia obtusifolia*, was planted here, as the writer found a wilt disease affecting it on James Island in 1899. No such disease appeared here. This weed has frequently been observed in fields where the cowpea disease was present, but has always been free from wilt, so that it is quite probable that the disease of cassia is distinct from the cowpea wilt, though the fungus causing it is closely related to the cowpea fungus.

Astragalus sinensis, *Lespedeza bicolor*, and *Vicia faba* were also planted, but failed to grow; so no results can be reported.

Seventeen varieties of cowpea were planted to test their resistance to wilt.

"*Turco fascula*," S. P. I. No. 3610, from Smyrna.—An early cowpea, which made a vigorous growth in the early part of the season, but was all killed by wilt before the end.

Cowpea from Alashehr, Asia Minor, S. P. I. No. 3627.—An early variety of medium growth and quite prolific; quite subject to wilt.

Cowpea from Smyrna, S. P. I. No. 3670.—An early sort of larger growth than the preceding and notably more resistant to the wilt disease, though not free from it.

Black Jurokusasage, S. P. I. No. 6311, from Japan.—A very early cowpea, and the most promising of the Japanese importations tested; plants medium or small, very prolific; pods long, 10 to 12 inches, with from 15 to 18 black seeds; subject to wilt and injured by dry weather, but nevertheless maturing a fair crop.

Kurakake, S. P. I. No. 6327, from Japan.—Early and small, but fruiting fairly well; pea white, with a black eye; badly injured by wilt and nematodes.

Kintohi, S. P. I. No. 6328, from Japan.—Early; a small, prolific variety, with small red seeds; injured by wilt and dry weather.

Black cowpea, from North Carolina.—This plant began to show the wilt disease before the middle of July and was badly injured by it, making a very small crop of peas. It was also much affected by the nematode.

Lady, from South Carolina.—A small white pea for table use. It made a good growth and appeared healthy and vigorous August 1. After this date it began to die from wilt and the whole plat was practically destroyed, no seed being obtained from it. The nematode was also bad on this variety.

Mixed, from Georgia.—Healthy till August, when it died very badly. At harvest time the majority of the plants were defoliated. Every hill had some dead, while in fully half the hills all were dead. No crop was matured. The nematode was bad on this plat.

Red Ripper, from Georgia.—This plat was badly injured by nematode and somewhat also by the wilt disease. It dropped its leaves badly, but ripened a small crop of seed. It appears to be partially resistant to the wilt, and selections from the resistant plants will doubtless prove more successful.

Southern, from North Carolina.—Earlier than the preceding varieties. It bore quite well and proved to be partially resistant to the wilt, more so, perhaps, than any other sort except the Iron. It was badly defoliated late in the season. Nematode swellings were found in abundance on the roots.

Speckled, from South Carolina.—Late and badly diseased with the wilt; very little crop matured; nematodes on every plant.

Taylor, from Virginia.—A vigorous grower early in the season. Later on it suffered badly from drought and was badly injured by wilt and nematodes, so that very little seed was obtained from this plat.

Unknown, from Georgia.—A medium early variety on which the wilt disease appeared very early. A large part of the plants were killed and the crop ripened was very light; nematodes abundant.

Wonderful, from North Carolina.—A vigorous grower; late in bearing. The injury from wilt was very great. Though a part of the plants retained their leaves practically no seed was matured; nematodes abundant on the roots.

Iron, from South Carolina.—There were four plats of this variety in different parts of the field, with other varieties in between, so that there was abundant opportunity for comparisons. Iron was almost entirely free from wilt throughout the season. It made a vigorous growth, and bore a large crop, while the other varieties mentioned above growing beside it were nearly a total failure. (Pl. II and Pl. III, fig. 2.) Careful examination of a large number of plants, made by the writer and by Mr. H. J. Webber, failed to show any wilt fungus except on occasional scattered plants. It was also especially noteworthy that this cowpea was almost entirely free from the root nematode. This point is treated in detail in the second part of this bulletin. During the dry weather in July and August, when other varieties were dropping their leaves and blossoms, the Iron did very well. Its powers of drought resistance were nearly as conspicuous as its resistance to disease, and the combined qualities certainly mark it as one of the hardiest varieties known.

The Iron cowpea is a compact vigorous plant, of medium size (Pl. III, fig. 1), somewhat trailing in habit, but less so than the Unknown. The foliage is dark green, with a peculiar bluish luster that distinguishes this variety from others. It is of the Clay type. The seeds are small and hard. The color is buff and somewhat variable, seeds of different shades being found in the same pod.

The plant begins to bloom in about two months from planting and continues up to frost. The crop is therefore ripened through rather a long season, which is something of a disadvantage, though it is partially compensated by the fact that the pods do not shell out in the field as freely as other sorts, and picking can therefore be deferred till late. It holds its leaves under adverse conditions of drought and disease better than any other kind tested, and is especially noteworthy for the way it remains green up to frost, very much later than other varieties. When cut for hay it sprouts freely from the stubble, and makes more second growth than is usual (Pl. IV, fig. 1).

The Iron cowpea has proved to be the solution of the wilt problem wherever it has been cultivated on "pea sick" lands in South Carolina, though more extended trials, now in progress by the Department, will be necessary to determine its value for other localities. The origin of the variety is uncertain. It was found in cultivation in Barnwell County, S. C., by Mr. T. S. Williams four years ago, and was brought to the attention of the Department by him.

Though it succeeds well on infected lands and produces good crops where others fail, it does not produce as much forage or seed as some of the other varieties, such as Unknown, and it will be desirable to carry on some plant-breeding work to remedy these faults, which the Department hopes to do in the future. It may also be possible, by selecting resistant plants of other varieties, to obtain new strains equally as good as the Iron.

EXPLANATION OF PLATES.

PLATE I. Specimens of Life-Preserver cowpea, showing different stages of the wilt disease; photographed July, 1901, Dillon, S. C.

II. Experimental field at Monetta, S. C., showing comparative resistance of the Iron cowpea, on the left, and the Speckled cowpea on the right; photographed September, 1901, by Mr. H. J. Webber.

III. Fig. 1. Plants of Iron cowpea grown on infected land, showing condition October 24, 1901, Monetta, S. C. Fig. 2. Row of select Iron cowpea, planted between Black and Taylor cowpeas on experimental field at Monetta, S. C., showing comparative resistance to the wilt disease; photographed September, 1901, by Mr. H. J. Webber.

IV. Fig. 1. Iron cowpeas growing between rows of asparagus in wilt-infected field in Monetta, S. C., showing second growth after cutting for hay; photographed October 24, 1901. Fig. 2. Iron cowpeas in peach orchard, showing how the variety remains green until frost; photographed October 24, 1901.

THE WILT DISEASE OF COWPEA.

IRON COWPEA ON LEFT, SPECKLED COWPEA ON RIGHT, SHOWING COMPARATIVE RESISTANCE TO WILT AND ROOT KNOT.

FIG. 1.—PLANTS OF IRON COWPEA, OCTOBER 26, 1901.

Taylor. Iron. Black.

FIG. 2.—IRON COWPEA VS. BLACK AND TAYLOR, SHOWING COMPARATIVE RESISTANCE TO THE WILT AND ROOT KNOT.

FIG. 1.—IRON COWPEA IN ASPARAGUS FIELD INFECTED WITH COWPEA WILT.

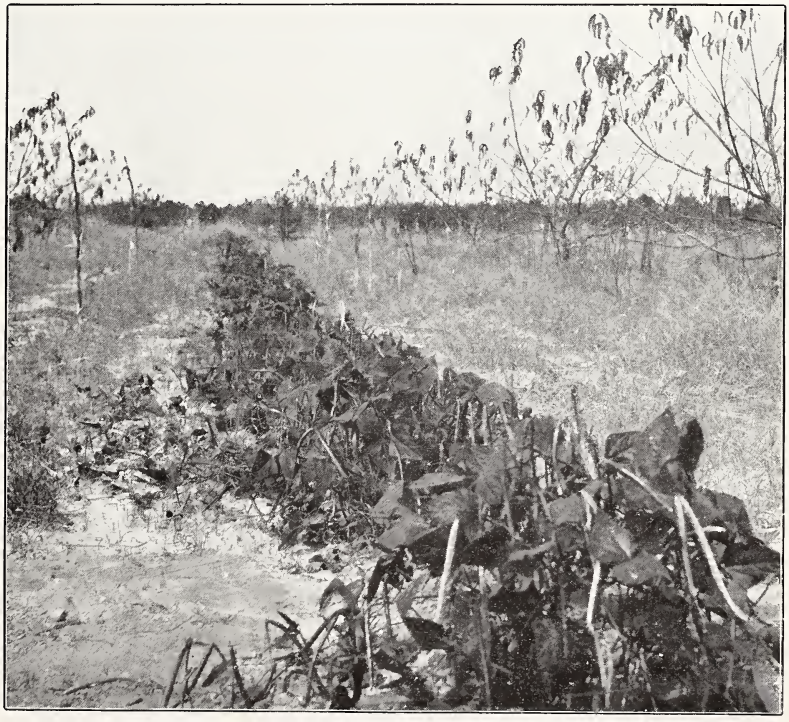

FIG. 2.—IRON COWPEA IN PEACH ORCHARD INFECTED WITH COWPEA WILT.

II. A COWPEA RESISTANT TO ROOT-KNOT (HETERODERA RADICICOLA).

By Herbert J. Webber, *Physiologist*, and W. A. Orton, *Assistant Pathologist*.

INTRODUCTION.

Root-knot, or root-gall, as it is ordinarily termed, is one of the most common and destructive plant diseases in the southern United States. The disease is caused by the attacks of a nematode, *Heterodera radicicola* (Greef.), Müll.,[1] which enters the roots and causes large galls. It is interesting to note that the nematode producing the root-knot of plants is closely related to the trichina of pork, which has become a household word and a universal terror.

DESCRIPTION OF THE DISEASE.

The characteristic external symptoms of the disease are the swollen, bead-like tumors produced on the roots. (Pl. VI.) Frequently the galls on badly diseased plants become so numerous that almost every root may be swollen to several times its normal size throughout almost its entire length. The organism attacks roots of practically any size, being common on both tap roots and smaller lateral roots. The surface of the gall is at first smooth, and later ordinarily becomes cracked, scurfy, and more or less decayed. There is a considerable variation in the forms of the galls on various plants, but there is a general similarity in all cases.

The nematodes, or nematode worms, as they are popularly called, though not true worms, when hatched from the eggs are embedded in the tissue of the old gall. From this they force their way through the tissue of the gall into fresh parts of the same root, where they take up their existence or force their way out of the old root into the soil and wander about until a satisfactory fresh root is found, into which they penetrate and form a new gall. They are so constituted that they can gradually make their way through the cells of a plant until they reach a satisfactory point for their development. Their irritation in the plant causes an abnormal enlargement of the tissue in their proximity, which leads to the formation of the large gall, which harbors and furnishes sustenance for the development of the organisms. The size of the gall is largely determined by the number of

[1] *Heterodera* is referred to in various publications under the generic names *Tylenchus* and *Anguillula*.

nematodes present. As new nematodes are hatched and take up their abode in fresh portions of the tissue the gall increases in size.

While the galls produced by nematodes are quite different from the bacterial root tubercles of leguminous plants and the root tumor of the peach and plum, they are nevertheless quite similar to certain root diseases, such as the swellings characteristic of "clubfoot" of cabbage (*Plasmodiophora brassicæ*), and the presence of the nematodes in the tissue forms the only absolutely sure determining character. Thin sections through the galls when examined under the microscope should show the eggs, larvæ, or cysts of the nematodes in some stage of development. The best descriptions of the development and metamorphosis of the root-knot nematode (*Heterodera radicicola*) known to the writers are those by Professor Atkinson,[1] then of the Alabama Experiment Station, and by Dr. G. E. Stone and Ralph E. Smith,[2] of the Hatch Experiment Station of Massachusetts. The reader is referred to these papers for further details of the development. According to Professor Atkinson, the length of time required for the completion of the entire life cycle in *Heterodera radicicola* is about one month. A knowledge of this fact is very important in applying the method of controlling the disease by planting catch-crops.

PLANTS AFFECTED.

In view of the possibility of breeding resistant strains of some plants, which will be discussed later, it becomes very interesting to note what plants are known to be affected by the nematode under consideration. Unfortunately, data upon this subject are rather incomplete. The following, which is one of the most trustworthy lists, is that given by Atkinson:[3]

Badly affected.	*Slightly affected.*
Solanum tuberosum (potato).	Amygdalus persica (peach).
Lycopersicum esculentum (tomato).	Ficus carica (fig).
Abutilon sp.	Vitis vinifera (grape, several varieties).
Vigna catjang (cowpea).	Solanum esculentum (eggplant).
Lotus corniculatus (bird's foot clover).	Physalis sp.
Helianthus annuus (sunflower).	Gossypium herbaceum (cotton).
Citrullus vulgaris (watermelon).	Hibiscus esculentus (okra).
Cucumis melo (nutmeg melon, citron).	Sida spinosa.
Brassica oleracea (cabbage).	Modiola multifida.

[1] Atkinson, Geo. F. Nematode Root-Galls. A Preliminary Report on the Life History and the Metamorphosis of a Root-Gall Nematode, *Heterodera radicicola* (Greef.) Müll., and the Injuries produced by it upon the Roots of Various Plants. Rept. Agr. Exp. Station, Auburn, Ala. Bul. No. 9, New. Ser., Dec., 1889.

[2] Stone, G. E., and Smith, Ralph F Nematode Worms. Hatch Exp. Sta., Mass. Agr. Col., Bul. 55, Nov., 1898.

[3] Atkinson, l. c., p. 49.

Badly affected—Continued.

Brassica campestris rutabaga (rutabaga)
Pastinaca sativa (parsnip).
Tragopogon porrifolius (salsify).

Slightly affected—Continued.

Cassia obtusifolia (coffee weed).
Phaseolus.
Lespedeza striata (Japan clover).
Melilotus alba (sweet clover).
Ipomœa tamnifolia.
Ipomœa lacunosa.
Clematis.
Phytolacca decandra.
Beta vulgaris (beet).
Amarantus retroflexus (careless weed).
Chenopodium anthelminticum (worm-seed).
Zea mays (corn).
Brassica rapa (turnip).
Marrubium vulgare (horehound).
Lactuca sativa (lettuce).

The above list was based on observations made simply at Auburn, Ala., and, according to Professor Atkinson, the presence of the nematode was determined microscopically in each case.

Dr. J. C. Neal[1] in his list of plants affected by this nematode in Florida enumerates 64 species, many of which are not given by Atkinson, but the above list will serve to show what widely different plants and families of plants are affected.

The same species of nematode affects many greenhouse plants in the North and frequently causes serious damage. The plants on which the most serious loss is produced under such conditions are the violet, rose, cyclamen, cucumber, and tomato.

EXTENT OF THE DISEASE.

The disease is evidently very common throughout the Gulf States and South Carolina, and may possibly extend farther northward. However, it will probably never become a serious malady north of this general region, except in greenhouses, as the nematode is killed by severe cold. Dr. Neal thought the northern extension to be not far from the January isotherm of 50°, as shown in No. 2 Isothermal Lines of the United States Signal Service, 1881. It certainly occurs much farther north than this, but data regarding its exact extent are very incomplete. The isotherm of 45° passes near Auburn, Ala., where Professor Atkinson's work was done; and Monetta, S. C., where the writers' observations were made, is probably north of this isotherm. In greenhouses in various parts of the North considerable damage is caused by the same nematode, and its control under such conditions has been made the subject of an exhaustive study by the Experiment Station of the

[1] Neal, J. C.—The Root-knot Disease of the Peach, Orange, and Other Plants in Florida. U. S. Dept. of Agr., Div. of Entomology, Bul. No. 20, Washington, 1889.

Massachusetts Agricultural College.[1] The same species of nematode is known to occur in many parts of the world, and it would seem to be world-wide in its distribution. The writers have observed the disease in many different places in Florida, Georgia, Alabama, and South Carolina, and know it to be of common occurrence in those States. On the cowpea (Vigna catjang) in South Carolina it is very common and certainly causes considerable damage in lessening the quantity of fodder and peas produced.

Its greatest damage in the case of the cowpea, however, is probably due to its secondary action in spreading the nematode to other plants. It is not uncommon to hear peach growers of the South condemn the practice of growing the cowpea in peach and plum orchards because of the probability of its spreading root-knot. In Florida, where the beggar weed (Desmodium molle), which is said to be free from root-knot, is largely used in orchards as a cover crop and as green manure instead of the cowpea, the loss is said not to be so great. In more northern localities, however, where the beggar weed will not succeed, we as yet have no leguminous plant similar to the cowpea which could be recommended to take its place in orchards.

Nematodes frequently occur in connection with the wilt disease, and there is much greater injury done in such cases than would result from either one alone, but the two diseases are not necessarily connected nor dependent on each other. This is proved by the large number of cases observed by the writers where the wilt disease has been very destructive to cotton, cowpeas, watermelons, and other plants on land free from the nematode.

Of the two diseases of the cowpea, the root-knot is at present relatively more important on account of its wider distribution, and the fact that it attacks a large number of other crops, while the wilt disease so far as known is not communicable to other plants. If cowpeas or some other crop equally susceptible to the nematode be planted on infected land, they become badly diseased, and the number of nematodes in the soil is greatly increased, to the great detriment of succeeding crops.

Many farmers have expressed to the writers their belief that the cultivation of cowpeas increased the amount of wilt disease in succeeding cotton crops, but an examination of such fields have shown that the injurious effect of the cowpea crop was due to its action in fostering the root nematode. For this reason the resistance of the Iron cowpea described below, to the nematode, gives it special value for cotton planters.

In South Carolina the opinion is prevalent among planters that when cowpeas are grown continuously on the same soil for several years in

[1] Stone, G. E., and Smith, Ralph E., l. c.

succession that some fields, or patches in certain fields, become "pea-sick," as it is expressed; that is, so affected that they will not produce a crop of cowpeas, though some other crop may mature perfectly. Such conditions are interpreted ordinarily as being due to the exhaustion of some nutrient element in the soil necessary for the growth of cowpeas that may not be necessary for other crops. The writers have examined many cases of this kind in South Carolina and Alabama and have invariably found that the trouble was due either to attacks of wilt disease or root-knot or to the combined action of both of these maladies.

METHODS OF TREATING ROOT-KNOT.

The methods of treating root-knot which have thus far been employed are far from satisfactory. The following short review of these methods is introduced here mainly to call attention to the difficulty in preventing the disease by the application of treatments. A fuller discussion of the various methods can be found in the bulletins of Atkinson and Stone and Smith above referred to. Three methods in general have been suggested, namely: (1) Soil sterilization; (2) the action of toxic chemicals; and (3) the preparation of the plants to better withstand injury.

Soil sterilization.—Treatment by soil sterilization would include both the freeing of the land from the nematodes when once infested and the hygienic and other measures that may be employed to keep soils free from them. When fields have been badly infested the nematodes can probably best be killed out by growing on the land crops known to be unaffected until the nematodes have been killed by starvation. A proper rotation would also tend to keep the disease in check. The most practicable plan would be to keep the land in corn, oats, wheat, or grass for at least two years, using the greatest care to keep out all weeds, as so many plants are affected by root-knot that the disease is liable to be carried over and spread through their agency. The difficulty of sterilizing soil by starvation is readily seen when it is realized that during the entire time absolutely all weeds and plants subject to the disease must be prevented from growing. While this method of treatment is of great importance, the difficulty of its application renders it far from satisfactory.

In keeping the soil free from the nematodes it is important to remember that the larvæ and eggs are very minute and are easily carried from infested fields and spread to uninfested localities. They may be carried in the soil clinging to the feet of man or animals or to tools, or they may be blown about in the dust by the wind and washed here and there during heavy rain storms. Their distribution by the wind is hardly within control, but considerable can be done to prevent their spread by animals and by water in drainage. In preventing the

spread of nematodes to perennials such as fruit trees the use of artificial, subterranean barriers which prevent the nematodes from passing freely through the soil to the tree has also been suggested, and while not altogether effective may be of some service. Such a barrier can be built around the tree, consisting of staves, scraps of galvanized sheet iron, or pieces of bark, placed close together. Burning brush or trash on the soil in sufficient quantity so that it is heated down for a foot or so has the effect of killing the nematodes, and places for planting susceptible trees can be sterilized in this way and reinfection partly prevented by artificial barriers. In greenhouses also heat is very effectively employed to sterilize the soil. In field operations frequent plowings in winter and in extreme dry spells have also been suggested as of benefit in destroying many of the larvæ in the soil by bringing them to the surface where they will be killed by freezing or by the action of the sun.

A unique method used to some extent by sugar-beet growers to reduce the numbers of the sugar-beet nematode (*Heterodera schachtii*) is that devised by Professor Kühn of trapping the larvæ by the use of catch plants. Strubell had shown that in this nematode about five or six weeks were required for the larvæ to reach maturity after entering the plant, and Kühn proposed to plant such crops as are selected most readily by the nematodes and at the end of a month, before eggs are produced, to pull them up and destroy them. At this time the oldest nematodes in the roots would not have produced eggs and the majority of them would have developed into motionless sacs, incapable of boring their way out, and would thus perish when the plants were removed from the soil. The crop of the catch plant can be used for forage or other purposes and thus partially pay for the expense of the treatment. Kühn's experiments have been characterized as a brilliant success, and some such method could doubtless be devised for the treatment of root-knot in this country, but so far as the writers are informed no careful experiments of this kind have so far been carried out with *Heterodera radicicola* where, according to Atkinson, the life cycle is much shorter, being about one month. Cobb,[1] in describing the occurrence of *Heterodera radicicola* in Australia recently, has suggested that mangels sown thickly and cowpeas would be promising to try as catch plants for this nematode.

Action of toxic chemicals.—The control of root-knot by the use of toxic chemicals is limited naturally to attempts to kill the larvæ in the soil, as it would seem to be impossible to kill them after they enter the plants without at the same time killing the plants. Neal and Stone and Smith in this country have made numerous experiments with

[1]Cobb, N. A.—Root-Gall. The Agricultural Gazette of New South Wales, XII, p. 1046 (Sept. 1901).

various chemicals, but without obtaining satisfactory results in any case.

Very many experiments have also been made with the nematode of the sugar beet (Rübenmüdigkeit), but the results thus far are mainly negative. No satisfactory chemical remedy has been discovered. Carbon bisulphide has proved to be effective in destroying the nematodes, but the expense of this treatment precludes its use on a large scale. The use of lime in large quantities has also been highly recommended, one or two tons per acre being used during the year in two or three applications.

The preparation of plants to withstand injury.—It has been learned by observation and experiment that certain chemicals tend to increase or diminish the disease owing to their effect on the plant. Highly nitrogenous manures which tend to cause a rapid growth of succulent, tender tissue, are said to increase the injury caused by root-knot, while heavy fertilization with sulphate or muriate of potash, which tend to produce a well-hardened, comparatively slow growth, is said to greatly lessen the injury.

THE USE OF RESISTANT VARIETIES AND STOCKS.

The first discussion which the writers have thus far found in literature of the possibility of controlling nematode diseases by the use of resistant varieties and stocks is that by Doctor Neal,[1] who says: "After all, I believe the use of trees that are not susceptible to the root-knot for stocks on which to graft or bud the susceptible varieties is the proper solution of the root-knot problem." Neal recommends the hardy bitter-sweet or sour orange as a species nearly proof against attacks of root-knot, and further states that *Citrus trifoliata* and the Satsuma or Onshiu orange seem to be resistant. In his list of plants affected by root-knot Neal includes the orange as one of the plants slightly affected. During a prolonged investigation of the diseases of the orange in Florida one of the writers dug up and carefully examined the roots of orange trees in all parts of the State, but was unable to find any trace of injury by nematodes. While negative evidence is always of doubtful value he is convinced that root-knot of the orange in Florida is at least of very rare occurrence. The resistance or nonresistance of any orange varieties or species under such conditions could hardly be conclusively determined.

According to Dr. Neal's statements, among grapes the *cordifolia* and *vulpina* races are largely free, while the *vinifera* and *æstivalis* groups are subject to the disease. He also states that the Wild Goose and Marianna plum stocks are largely immune. The evidence on which Neal's claims are based is not sufficiently given to enable one to

[1] Neal, l. c., p 22.

judge of their value. If he is correct, their value has not been thoroughly appreciated. Some features of his investigations have been questioned, and this may have led to his valuable suggestion regarding the use of resistant strains being improperly appreciated.

Zimmerman has also pointed out that the nematode attacking the coffee plant in Java only exceptionally affects Liberian coffee (*Coffea liberica*), but is very serious on Arabian coffee (*C. arabica*).[1] In an experiment in which healthy trees of both species were grown for over five months in the same pots with badly diseased plants, 95 per cent of the healthy trees of *C. arabica* became infected, while only 59 per cent of those of *C. liberica* showed the disease. The Arabian coffee sells in the market at a higher price than Liberian coffee, and Zimmerman recommends controlling the disease by grafting Arabian coffee upon the more resistant Liberian stock. This he says can be satisfactorily accomplished with the loss of only a few plants. The same method of controlling the coffee nematode has also been recommended more recently by Bonquet de la Grye.[2]

The only other suggestion regarding the use of immune strains in the treatment of nematode diseases that has come under the notice of the writers is that made last year by Wilfarth,[3] who conducted somewhat extensive experiments to demonstrate the possibility of breeding strains of the sugar beet resistant to nematodes. He states that in badly infected fields where the beets are abundantly infested there are always some individuals which show very few or almost no nematodes. In one of Wilfarth's experiments a large box was filled with soil which was thoroughly infested artificially with nematodes. In this box 205 beets were grown. Tests made from time to time showed the nematodes to be very abundant. The plants were examined at three different times to determine whether there was any difference in the time of infection. In general the plants were abundantly infected, about 18 per cent were badly infected and 28 per cent but slightly infected. Among those slightly infected were many with only a few nematodes. The percentages of badly and slightly infected plants at each harvesting period were about the same. From the results of the experiment it was inferred that the nematodes do not enter all beets indiscriminately, but find certain differences which render some beets more agreeable than others.

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[1] Zimmerman, A. Het Groepsgewijs afsterven der Koffie heesters in gesloten plantsoenen. Teysmannia, 1897, 23 pp.; also De Nematoden der Koffiewortels. I. Mededeelingen uit's Lands Plantentuin. 1898. No. 27, 64 pp. (German review in Centralbl. f. Bakt. Parasitenk. u. Infek. 2 Abt. 5, 415).

[2] Bonquet de la Grye. La Génération des Plantations de Caféières dans les Antilles. Bull. de Séances d. l. Soc. Nationale d'Agr. d. France. 1899. 683–687.

[3] Wilfarth, Prof. Dr. H. Ein neuer Gesichtspunkt zur Bekämpfung der Nematoden. Zeitschr. d. Ver. d. Deut. Zucker-Industrie. Lieferung, 529, pp. 195–204. Feb., 1900.

In another experiment 100 good, normal beets, wholly free from nematodes, were selected from a field free from nematodes and stored during the winter. In the spring each of these was cut into from ten to sixteen pieces of equal size, which were divided into two equal lots, the pieces from each beet being kept separate under the same number. These were then planted in a field badly infested with the nematodes, the two lots from the same beet being planted in different places. When the plants grown from these pieces were harvested and the abundance of nematodes observed they were found to follow a definite rule of abundance or susceptibility in all of the plants grown from cuttings of the same mother beet. For instance, the four pieces of beet No. 16, which stood in one row, all had very few nematodes, while the other beets on either side in the same row and in adjoining rows were uniformly badly infected. The four pieces of the same mother beet planted with the second lot under the same number were also but slightly infected. It can thus be safely concluded that this was a case of genuine resistance to the nematode. A number of the beets showed about the same degree of resistance, while others were resistant in a much less degree. The investigation indicates that certain beets possess a specific attraction or repulsion for the nematodes, and the latter can be explained, says Wilfarth, only by assuming that a certain protective apparatus or device exists in the beet which keeps the nematodes out. The injurious influence of the nematode shows in the reduced size, malformation, and diminished sugar content. If, therefore, we select from a badly infested field those beets for mothers which do not have these characters and are well-formed and rich in sugar content, we will secure the resistant beet that we seek. Wilfarth advocates selecting resistant mother beets on badly infested soils and growing seed from these on similarly badly infested soils, and again selecting those beets least affected among the progeny to use as mothers. By continuing such selections he believes that thoroughly resistant strains can be bred.

A RESISTANT COWPEA.

The above review of the methods of controlling nematode diseases is given to show the present understanding of the malady. No method of treatment has yet been devised that can in any way be considered satisfactory, and the breeding or discovery of resistant strains remains as yet largely as a suggestion. It is thus highly important that further information be obtained, particularly in regard to the resistance of strains of plants subject to the disease and the possibility of producing such strains by breeding. Under these conditions it is highly gratifying to be able to announce the discovery of a variety of cowpea which under existing conditions seems to be almost absolutely immune to the disease.

Its resistance was brought out by the experiments with cowpeas and other leguminous crops described in the first part of this bulletin. These varieties were planted on the farm of Mr. T. S. Williams, Monetta, S. C., on land infected with the wilt fungus, in order to determine their resistance to that malady. This land proved to be thoroughly infested with the root nematode, though that was not known when the field was selected. In making the examination of the cowpea roots for the wilt fungus it was observed that the great abundance of nematode galls on the roots of many varieties more or less complicated the matter, as it was difficult to determine what proportion of the injury observable was to be ascribed to the wilt and what to root knot. Some care was therefore exercised in each case to determine the abundance of the nematodes on each variety grown. The field on which the plants were grown was a level area, slightly lower than most of the surrounding land, but apparently thoroughly drained. The different varieties and species were planted in rows about 200 feet long and from one to four rows of a variety in a place. Of several of the varieties two plats were grown in the same field, but separated some little distance from each other. All the species and varieties of leguminous plants grown, except one, that were in proper condition when the observations were made were found to be affected with root-knot, and on the majority of varieties the disease was very bad. One variety of cowpea, the so-called "Iron," was so strikingly free from infection as to attract immediate attention. Two plats of this variety were grown, one of four rows and another of eleven rows, so that abundant opportunity was furnished for observation. Numerous plants were dug up here and there in each plat and only one individual plant was found which showed any trace of root-knot. The plat of four rows was in the center of the field, and on one side adjoined the plat of the "Unknown" cowpea and on the other side the "Speckled" cowpea. Both of these varieties were very badly affected with the root-knot, practically every plant being badly diseased, so that there can be no doubt that the Iron, growing only a few feet away, had every opportunity to become infected had it not been resistant to the nematode. It is interesting to note that the same variety is very resistant to wilt also. In a careful search through the same plat not a plant was found that exhibited the characteristic symptons of wilt, though this disease was also abundant in the two varieties growing on either side. The immunity of the Iron cowpea to wilt has been discussed in detail by one of the writers[1] in the preceding article of this bulletin.

The combined effect of root-knot and wilt on the cowpeas was very serious. The two plats of the Unknown and Speckled cowpeas on either side of the Iron were almost entirely destroyed. When exam-

[1] Orton, W. A. The Wilt Disease of Cowpea and Its Control. U. S. Dept. Agr., Bureau Plant Industry. Bul. No. 17, Article I, pp. —.

ined a large number of the plants were dead, showing by the symptoms that they had succumbed to the combined effect of the two diseases. Many of the plants had dropped all their leaves but were still green, while some had a comparatively few leaves still attached and green. All of the plants were small and stunted, and in the case of the Unknown had been so badly injured that no fruit was produced. The other variety, the Speckled, had produced a small crop of peas but was comparatively a failure. The difference in appearance between these two plats and the plats of the Iron cowpea was most striking. The Iron had made a fine growth, was wholly free from disease, and was fruiting abundantly, being both in flower and fruit at the time examined. In the other plat of the Iron cowpea all of the plants examined were found to be equally resistant to those in the plat just described. The second plat was an exterior one at one side of the field, and thus had plats only on one side with which it could be compared. The plat next to it on this side was of Yainari (*Phaseolus mungo-radiatus*), an imported Japanese plant, which on careful examination was found to be very badly infested with nematodes, almost every plant showing their effects. It seemed to be free from attacks of the wilt fungus, however, as no plants showing this disease could be found in the plat.

Only a short distance from the experimental plats a comparatively large field of the Iron cowpea was growing, which was examined and a number of plants pulled up without finding any trace of nematode infection. In another near-by field of an ordinary variety the root-knot was found in considerable abundance.

The Iron cowpea is quite distinct in character from any other variety known to the writers. One peculiarity is its habit of continuous blooming—it may have flowers and ripe fruit on the same plant. As a result of this it continues to ripen its seed over a considerable period and retains its foliage meanwhile. This is a decided disadvantage if the peas are grown for their fruit, but if the crop is grown for forage the attendant character of retaining their leaves green until frost allows the grower greater latitude in harvesting, and this may be a decided advantage. While some other varieties of cowpeas possess some qualities superior to the Iron, the latter is surely a good variety for general purposes and is especially valuable on account of its disease-resistant qualities. The variety and its history have been more thoroughly described by one of the writers[1] in the first article of this bulletin.

The varieties of cowpeas grown on which observations were made were the Wonderful, Southern, Black, Whip-poor-will, Lady, Red Ripper, Taylor, Unknown, Speckled, Kurakake (an imported Jap-

[1] Orton, W. A., l. c.

anese variety), Section of Seed and Plant Introduction No. 6327, and Iron. In all these varieties except Iron it was difficult to find a single plant showing what could be considered normal roots and bacterial tubercles. (Pl. VI.) The roots of the Iron were uniformly fine and slender, showing no indication of root galls produced by nematodes, but abundant nitrogen tubercles here and there, many of them remaining attached to the plants when dug up, though many were doubtless pulled off in removing the plants from the soil. (Pl. V.)

The Iron cowpea, because of its resistance to wilt and root-knot and hardiness in other respects, is certainly one of the most valuable varieties of cowpeas known, and, with our present knowledge, is to be highly recommended for cultivation on all soils that are known to be infested with one or the other of these diseases. On soils free from these diseases some other variety may give better results, though the Iron is a good hay variety. In peach and plum orchards and places where it is feared the cowpea would induce the spread of root-knot the Iron variety can be grown without danger. It can be recommended without reserve as the safest variety of cowpea known for growing in such cases.

It is hardly to be expected that the Iron will prove absolutely immune to attacks of nematodes under all conditions. It is well known that when the larvæ can find no suitable or agreeable food they will enter plants ordinarily free from their attacks. The cause for the resistance of the Iron cowpea is under investigation and will form the subject of a later report. It is impossible, with our present knowledge, to state whether or not the larvæ would be able to live and mature if they forced their way into the roots. It is certainly marvelous that closely related varieties of cowpeas should show such striking difference in their susceptibility to root-knot, when such a large number of species of plants belonging to widely different families are known to be attacked with apparently equal readiness by the nematode.

It is a matter of doubt whether the Iron will retain the same degree of immunity for an indefinite period. Changes in climate, soil, and manurial conditions may induce changes which would impair its degree of immunity. Professor Atkinson[1] mentions a case of variation in *Amarantus spinosus* which is interesting in this connection. This plant he finds to be free from nematode injury at Auburn, Ala., even in the immediate neighborhood of other badly diseased plants, while Dr. Neal reports the same species in Florida as the "most dreaded and destructive agent in the spread of root-knot." Sorauer[2] also refers to an interesting case of barley, which ordinarily is considered immune to attacks of the sugar-beet nematode (*Heterodera schachtii*). For three successive years a piece of badly infested land was sown

[1] Atkinson, l. c., p. 46.

[2] Sorauer. Pflanzenkrankheiten.

with barley, and for the first two years no noticeable injury was produced. The third year, however, the crop was destroyed a short time before harvest by attacks of nematodes.

Should the Iron cowpea lose its power of resistance when cultivated under different conditions, or after an extended period of cultivation on infested soil, it could probably be brought back to its full degree of immunity by a few generations of seed selection from the most resistant plants. Such selection could be easily made by pulling up, at the time of harvest, a large number of the plants grown on infested soil and taking seed from those found to be the least affected by the disease.

A number of leguminous plants were grown in the same experimental field as the cowpeas, on nematode and wilt infested soil, and the following are observations in regard to the abundance of nematode galls found on the roots of these:

Glycine hispida (Soy bean).
Best Green, S. P. I.[1] No. 5766, badly affected.
Early Black, S. P. I. No. 5039, badly affected.
Green Medium, S. P. I. No. 6335, badly affected.
Bakaziro, S. P. I. No. 6336, badly affected.
Dolichos lablab.
Purple Dolichos. S. P. I. No. 6320, badly affected.
White Dolichos, S. P. I. No. 6319, badly affected.
Phaseolus mungo-radiatus.
Muroran bean, S. P. I. No. 6318, badly affected.
Yainari bean, S. P. I. No. 6321, badly affected.
Mucuna utilis (Velvet bean).
Seed from two sources, S. P. I. Nos. 4333 and 5066, considerably affected.
Canavalia ensiformis.
White Natamane, S. P. I. No. 6323, badly affected.

For a more detailed statement in regard to the characters and success of the above plants the reader is referred to Part I of this bulletin.

THE BREEDING OF NEMATODE-RESISTANT PLANTS.

The cases of nematode-resistant plants and varieties known show clearly that certain plants possess qualities which render them unsuitable to the nematodes without at the same time materially impairing their value for cultivation. It would thus seem that nature has put into our hands the means of controlling this serious malady. In pulling up numerous plants of various cowpea varieties in making the examination above described a considerable variation in the degree of infection of different plants of the same variety was easily observable. Some plants were very badly diseased and others but slightly diseased.

[1] S. P. I. numbers referred to are those given by the Section of Seed and Plant Introduction of this Department.

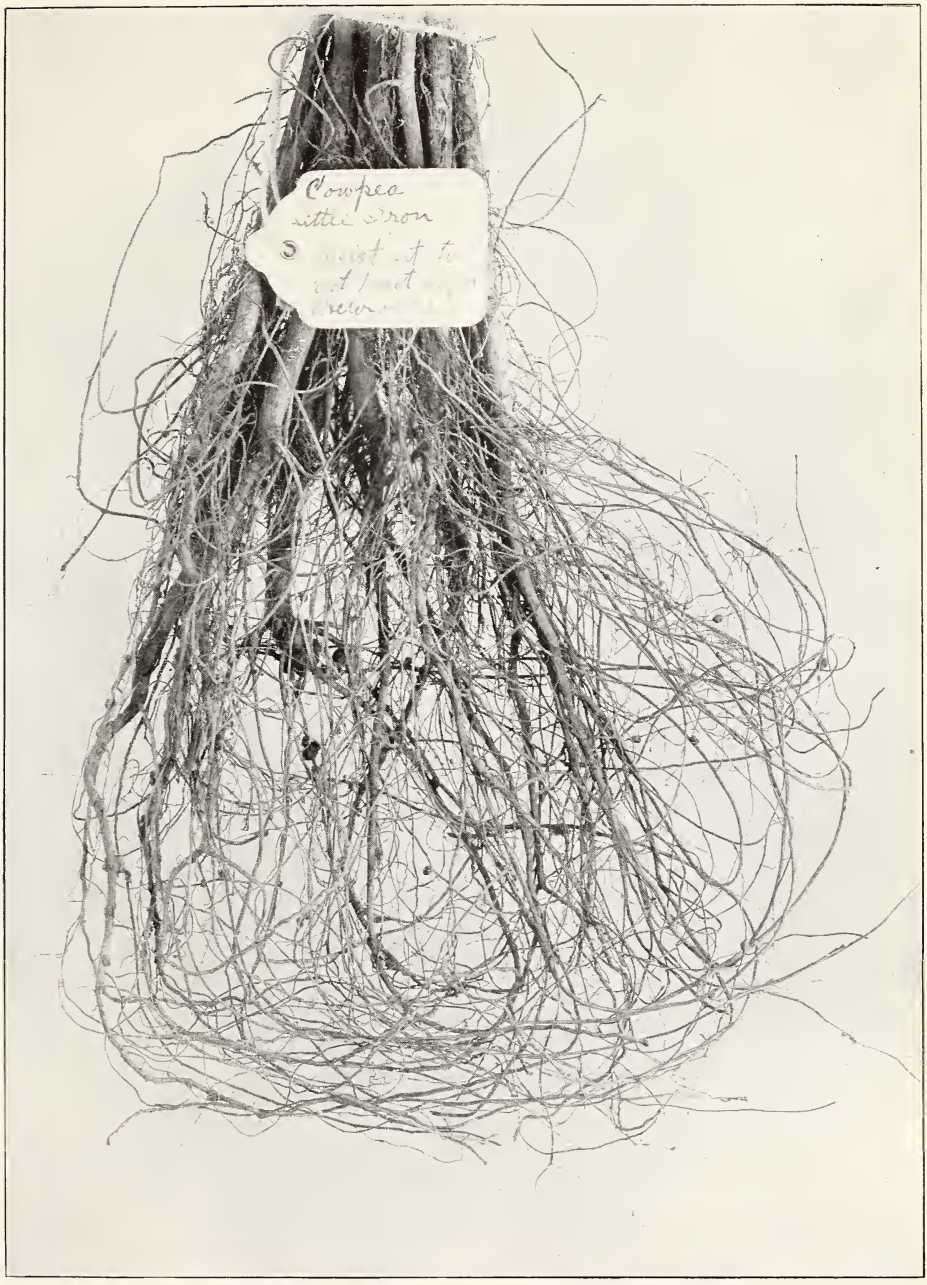
Whether this variation was due to accident or to inherent differences in the plants could not be determined, but it seems probable that a selection of seed from such slightly diseased plants continued through several generations, the plants being grown continuously on infested land, would ultimately lead to the production of an immune strain. The possibility of breeding nematode-resistant sugar beets has already been pointed out by Wilfarth, as indicated above. Mr. P. H. Dorsett informs the writer that in violet houses where the soil has become infested with root nematodes, he has observed a great difference in the susceptibility of different plants. If this is the case, we doubtless have here also the possibility of breeding resistant varieties.

The experience of the Department of Agriculture in breeding varieties of cotton resistant to wilt, and that of the French vineyardists in breeding grapes immune to *Phylloxera*, black rot, chlorosis, etc., shows how rapidly results of this nature can be obtained when intelligence is used in combining and selecting the best individuals. It may be possible to breed varieties of peaches, potatoes, tomatoes, cotton, etc., that will be resistant to root-knot, and we have here an interesting, extensive, and important field for experimentation.

EXPLANATION OF PLATES.

Plate V. Roots of Iron Cowpea resistant to Root-knot. The ordinary nitrogen tubercles are shown here and there, but these are very different in form from nematode galls.

VI. Roots of Wonderful Cowpea, attacked by Root-knot. These were taken from the same field as the roots of the Iron Cowpea, illustrated in Plate V.



ROOTS OF IRON COWPEA. RESISTANT TO ROOT KNOT.

ROOTS OF WONDERFUL COWPEA FROM SAME FIELD AS THOSE IN PLATE V, ATTACKED BY ROOT KNOT.

BULLETINS OF THE BUREAU OF PLANT INDUSTRY.

The Bureau of Plant Industry, which was organized July 1, 1901, includes Vegetable Pathological and Physiological Investigations, Botanical Investigations and Experiments, Grass and Forage Plant Investigations, Pomological Investigations, and Gardens and Grounds, all of which were formerly separate divisions, and also Seed and Plant Introduction, The Arlington Experimental Farm, Tea Investigations and Experiments, and the Congressional Seed Distribution. Beginning with the date of the organization of the Bureau, the independent series of bulletins of the Division of Vegetable Physiology and Pathology, the last number of which was 29, and also of each of the other divisions, were discontinued and all are now published as one series of the Bureau.

The bulletins so far issued in this series are:

No. 1. The Relation of Lime and Magnesia to Plant Growth, 1901.
2. Spermatogenesis and Fecundation of Zamia, 1901.
3. Macaroni Wheats, 1901.
4. Range Improvement in Arizona, 1901.
5. Inventory No. 9, Seeds and Plants Imported through the Section of Seed and Plant Introduction, 4351–5500, 1902.
6. A List of American Varieties of Peppers, 1902.
7. The Algerian Durum Wheats: A Classified List, with Descriptions, 1902.
8. A Collection of Economic and Other Fungi Prepared for Distribution, 1902.
9. North American Species of Spartina, 1902.
10. Records of Seed Distribution and Cooperative Experiments, 1902.
11. Johnson Grass: Reports of Investigations Made during the Season of 1901, 1902.
12. Stock Ranges of Northwestern California: Notes on the Grasses and Forage Plants and Forage Conditions, 1902.
13. Experiments in Range Improvement in Central Texas, 1902.
14. The Decay of Timber and Methods of Preventing It, 1902.
15. Forage Conditions on the Northern Borders of the Great Basin, 1902.
16. A Preliminary Study of the Germination of the Spores of Agaricus Campestris and other Basidiomycetous Fungi, 1902.